The Role of Human Capital in Economic Development: Evidence from Taiwan*

Yih-Chyi Chuang

National Chengchi University

The use of Taiwanese industrial data to investigate two potentially important roles of human capital on long-run economic growth (i.e. factor accumulation and technology progress), we find that human capital accounts for 46% of output growth in aggregate manufacturing industry and from 23 to 84% in two-digit industries. Significant knowledge spillover effects were found within Taiwan's manufacturing sector. For aggregate manufacturing, a roughly 29% of total rate of return to education gives a private return of 7% while the external knowledge spillover effect is 22%. For the two-digit industries, the inter-industry effect of education measures two to three times its intra-industry effect. Contrary to the Lau-Young proposition, we find that technology change in terms of knowledge spillover contributes 39% to the output growth of Taiwan's aggregate manufacturing and from 12 to 42% to that of the two-digit industries. Our results also suggest that, in the presence of externalities, growth accounting based on macro data may be misleading in interpreting the sources of growth.

In addition, the case study of Taiwan suggests that opening trade broadens opportunities, and hence increases the return on human-capital investment. However, our estimation results also suggest that in terms of capturing the growth benefits from trade, threshold levels of human capital exist in most industries.

I. Introduction

In recent endogenous growth literature, human capital has been broadly cited as a principal engine of growth (e.g., Romer, 1986; Lucas, 1988; Becker, Murphy and Tamura, 1990; Rebelo, 1991; Stokey, 1991a). Several cross-country empirical studies also support the importance of human capital in explaining growth (e.g., Barro, 1991; Mankiew, Romer and Weil, 1992; Benhabib and Spiegel, 1994). Human capital not only serves as an input in production but also determines technological progress.[1] Benhabib and Spiegel (1994) and Gould and

* The author would like to thank an anonymous referee for helpful comments and suggestions.

1. For instance, human capital may convey knowledge spillover as in Lucas (1988), Romer (1990b) and Grossman and Helpman (1991). In catch-up models, a large stock of human capital also implies a better quality of labour in absorbing innovative information as well as imports of foreign technology. See, e.g., Nelson and Phelps (1966) and World Bank (1991).

Ruffin (1995) identified these two important roles of human capital in determining long-run growth rates in their cross-country studies.

By considering the improvement of quality or human capital embodied in labour, Tallman and Wang (1994) found that human capital alone contributed 45% of Taiwan's economic growth for the period 1965–1989. Moreover, they found that the total contribution of raw labour, physical capital and human capital can account for 90% of Taiwan's economic growth. This result corresponds to the finding of Young (1995) and Lau and Kim (1992) of nearly zero total factor productivity (TFP) growth for the four Asian NICs. That is, factor accumulation itself accounts for most of the rapid economic growth of the Asian NICs!

Current cross-country studies which suggest a fairly prominent role for TFP growth (with or without a human capital component) group suffer a number of drawbacks as a group.[2] Country case studies, on the other hand, suggest that the (often prominent) role of human capital in growth operates only as direct factor accumulation, rather than through spurring a country's technological progress. Because of this conceptual and empirical gap, this paper evaluates the role of human capital in Taiwan's economic development from both factor accumulation and technological enhancement perspectives. Pinpointing the actual sources of Taiwan's rapid postwar economic growth – which has been accompanied by successful industrialization and trade liberalization – remains a difficult but important task. To this end, we focus on the effect of human capital at aggregate and two-digit industries levels. In addition, the possible effect of trade on human capital accumulation is also considered.

The main finding of the paper is that, above and beyond its role as a direct factor in production, human capital has played a prominent role in fostering technological progress, particularly as Taiwan's economy shifted towards an open regime. Human capital accounts for 46% and from 23 to 84% of manufacturing's output growth at the aggregate and two-digit industry levels, respectively. Furthermore, over 50% of human capital's contribution at the two-digit industry level stems from knowledge spillovers. That is, contrary to the Lau-Young proposition, we find that for Taiwan's economy, the technological change stemming from disembodied human capital and knowledge spillovers is far from negligible. Our results also suggest that in the presence of externalities, growth accounting based on macro data may be misleading in interpreting the resources of growth. In addition, Taiwan's case study strongly suggests that opening trade widens opportunities and, hence, increases the return on human capital investment. Trade is conducive to knowledge spillover and technological learning, and a large stock of human capital enhances the capabilities for absorbing and digesting new technology.

2. For example, measurement problems and sensitivity to sampling of a group of countries are considered. Tallman and Wang (1994) discussed these drawbacks. See also Solow (1994) and Pack (1994) for criticisms of current cross-country empirical studies.

The rest of this paper is organized as follows. Section II outlines Taiwan's postwar growth experience. Section III sets up the empirical model and discusses the data used in the regression analysis. Section IV presents the estimation results. Concluding remarks are made in Section V.

II. Taiwan's postwar growth experience

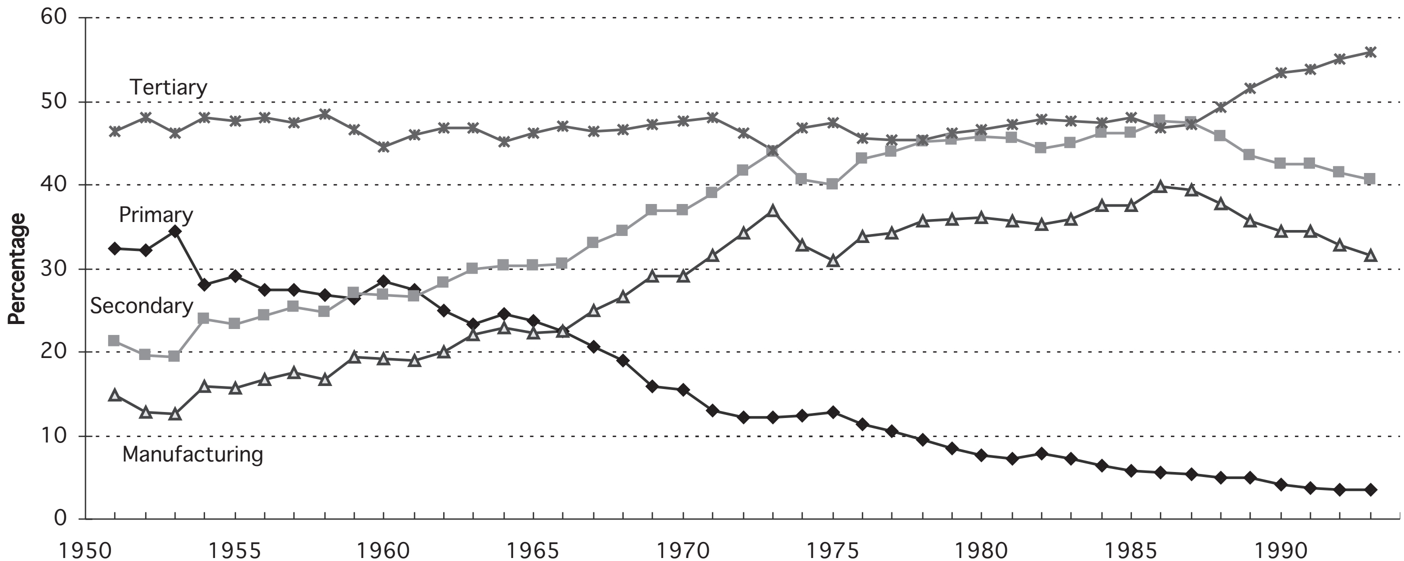
In the most general terms, Taiwan's postwar growth experience can be addressed by focusing in turn on three economy-wide phenomena. These features of Taiwan's economic growth over the past four decades have been successful industrialization, heavy dependence on international trade and persistent accumulation of capital and improvement in human resources.

(a) Taiwan is an island of 35,873 square kilometres only a quarter of which is arable. Natural resources are limited and coal is the most important mineral resource, estimated at about 700 million metric tons, only one-third of it economically recoverable. Historically, Taiwan was a colony of the Netherlands from 1624 to 1662 and of Japan from 1895 to 1945. Before World War II, as with most developing countries, Taiwan was characterized as a traditional agrarian economy, with rice and sugar being the two major agricultural products. However, since the end of World War II, Taiwan's economy has grown by leaps and bounds, as it successfully transformed itself from an agriculturally-oriented economy to an industrially oriented one with, must recently, the subsequent rise of the advanced service industry sector.

From 1953 to 1993, the annual average economic growth rate in Taiwan measured an impressive 8.7% (6.3% for per capita GNP).[3] The contribution of agriculture to GDP has declined steadily from 34.45% in 1953 to 3.46% in 1993. Industry's share increased annually from only 19.39% in 1953, to overtake agriculture in 1962. It reached its maximum value of 47.64% in 1986 but declined slightly from the late 1980s. The manufacturing trend was roughly analogous to that for industry, while the share of the services sector remained relatively stable with a gradual rise at the very end of the period. Figure 1 depicts the patterns of structural change. Until to 1970, the food industry had the highest share of GDP amongst all two-digit industries in the manufacturing sector, while the textile and clothing industries were the next highest. In fact, the share of the food industry began to decline after 1957 while that of textiles remained relatively stable at around 14%. However, the share held by the electrical machinery industry started from below 5% in the early 1950s, then surged from 1963, and consistently increased, taking first place from textiles in the mid 1970s. These are indicative of general trends during the industrialization process in Taiwan: a structural shift from light industry to capital goods industry, and the transition from a labour-intensive to technology-intensive production process.

3. All the figures referred to in this section are calculated from the *Taiwan Statistical Data Book* and figures in real terms are measured at 1991 constant price.

Figure 1 Distribution of GDP by Industry



(b) As government policy moved from import substitution in the early 1950s, through export-promotion beginning in the late 1950s, and then onto more aggressive trade liberalization in the 1980s, the dependence of Taiwan's economy on foreign trade increased tremendously, particularly with respect to advanced countries. From 1960 to 1993, the average annual growth rate of real exports was 15.4% (13.7% for real imports). The share of exports to the OECD countries consistently increased from 58% in 1962 to 78% in 1973, declined slightly to 65% in 1980, and then moved up again to maintain an average level of 70%. Imports from the OECD countries share much the same pattern as exports, except that they reached a high of 80% in the 1960s. Trade structure also changed enormously. Before 1960, over 50% of exports were processed agricultural products. However, since then, the composition of exports altered significantly towards industrial products. The share of industrial products was only 8.1% in 1952, but later surged to 46% in 1965 and 78.6% in 1970; thereafter, following a moderate increasing trend, it reached 96% in 1993. Imports for the 1952–1993 period consisted of over 60% agricultural and industrial raw materials due to the scarcity of natural resources. The share of capital goods in total annual imports increased from 14.2% in 1952 to 29.3% in 1965, hovered above 30% until 1975, and then gradually declined to 15.45% in 1993.

(c) As the economy matured and expanded outwardly, private savings also increased. The savings rate (i.e., gross national savings divided by GDP) increased from 15.3% in 1952 to 32.1% in 1972 and then remained stable at approximately 33% until 1990. In addition to domestic savings, domestic investment can be financed by foreign capital inflow. Before 1961, US aid was the primary source of Taiwan's domestic investment.[4] However, such inflows were dwarfed by the increase in domestic savings which really enabled the economy to finance its accumulation of physical capital. From the early 1960s to the early 1970s, domestic national saving was almost entirely devoted to meeting the demands of domestic investment. Since the mid 1970s, however, domestic savings have outpaced domestic investment, reflecting the sustained trade surplus in Taiwan's current account.

Investment in human capital accumulation was also remarkable. Between 1952 and 1993, the average annual growth rate of population was 1.7%. Since 1960, the labour participation rate has been relatively stable, remaining between 56 and 59%, and the unemployment rate has never exceeded 3% since 1965. The proportion of students in the total population increased from 14.6% in 1952 to 27.8% in 1972, and then slightly declined to 26.0% at the end of the 1970s, remaining stable around 25.5% after 1980. Moreover, the proportion of student in higher education to total number of students increased from 0.8% in 1952 to 10.9% in 1993. Primary and secondary school enrolment rates (numbers of persons enrolled as a percentage of age group) were 84% and 27.4%, respectively, in 1952. However, by 1975, the primary school enrolment rate had reached

4. Between 1951 and 1968, Taiwan received nearly US$1.5 billion in aid from the United States.

99% and the same level was attained for secondary school enrolment by 1985. Enrolment rates for higher education have also demonstrated an increasing trend over time, rising from below 10% in 1960 to 56.1% in 1993. Such figures have clear implications for the quality of Taiwan's workforce. The distribution of employed workers having completed primary, secondary, and tertiary schooling was 55.0%, 14.9%, and 3.9%, respectively, in 1964. However, the correspondary figures in 1993 were 26.1%, 51.8%, and 18.0%, respectively, indicating an unequivocal upward shift in the quality of the labour force.

We now turn to the discussion of the methodology which will be required to disentangle these phenomena and their effects on growth.

III. Empirical Model and Data Measurement

For our empirical study, we adopt the conventional Solow-type production function approach.[5] As emphasized in Lucas (1988), the accumulation of human capital not only enhances the quality of labour but also directly generates technological progress. Therefore, in order to capture these two important roles played by human capital the effects of embodied and disembodied human capital are incorporated into the neoclassical production function. Assuming the production function has the following form:

$$Y_t = A(H_t)K_t^{\alpha}(H_t L_t)^{\beta} \tag{1}$$

where Y denotes real output, K represents physical capital, L is raw labour, H denotes the workers' average level of human capital (HL, therefore, represents effective labour or labour in efficiency units), A represents the technological factor which is also allowed to depend on the stock of human capital (capturing the role of human capital as the engine of productivity growth), and α and β denote elasticities of capital and labour, respectively. Let technological change, driven by the stock of human capital, evolve according to[6]

$$A(H_t) = A \cdot e^{\gamma H_t} \tag{2}$$

Substituting (2) into (1) and taking natural logs yields

$$\mathrm{Ln}Y_t = \mathrm{Ln}A + \alpha\,\mathrm{Ln}K_t + \beta\mathrm{Ln}\,(H_t L_t) + \gamma H_t \tag{3}$$

Note that γ captures the external effect of human capital mainly through knowledge spillovers and technology enhancement. However, if we consider human capital as purely disembodied in labour, a variation of Equation (3) gives

5. The use of a production function approach to test the effect of human capital is common in the literature, see, e.g., Tallman and Wang (1994), Benhabib and Spiegel (1994), Lau et al. (1993) and also Gundlach (1997) for a survey.

6. The association of the stock of human capital to productivity can be derived either by innovation or a learning-by-doing model, see, e.g., Romer (1990b), Grossman and Helpman (1991), Stokey (1991a) and Lucas (1990).

$$\mathrm{Ln}Y_t = \mathrm{Ln}A + \alpha \mathrm{Ln}K_t + \beta \mathrm{Ln}L_t + \phi H_t \tag{4}$$

Note that, on the pattern of Mincer (1974), the formulation of Equations (3) and (4) enables us to make direct estimations of the external and total rates of return to human capital investment (γ and ϕ) respectively for the whole economy.[7] Thus, the economy-wide private rate of return to human capital can be derived indirectly by the difference of ϕ and γ. For analysis at the industry level, we can further decompose the external effect of human capital into intra-industry (own-industry) and inter-industry effects. This gives

$$\mathrm{Ln}Y_{it} = \mathrm{Ln}A_i + \alpha' \mathrm{Ln}K_{it} + \beta' \mathrm{Ln}(H_{it}L_{it}) + \delta H_{it} + \kappa \hat{H} \tag{5}$$

where i is an index for industry, $\hat{H}$ denotes stock of human capital at the aggregate manufacturing level, and δ and κ capture the intra- and inter-industry knowledge spillover effects, respectively. Equations (3), (4) and (5) are our empirical models for estimating the effect of human capital on the economy. Moreover, based on the estimated coefficients and the growth rates of each factor input, according to traditional growth accounting we can further calculate the contribution to economic growth from each input.[8]

However, Taiwan has successfully switched to an outward-oriented economy since the early 1960s. Recent growth literature has shown that trade may affect a country's economic growth[9] and it may also interact with human capital accumulation. A better educated labour force adapts new technologies and absorbs new information more effectively.[10] Stated more simply, opening trade broadens opportunities, thereby raising the rate of return to education. Therefore, by taking this into account we also include the trade variable and its interaction term with human capital in our regression analysis.

Empirically variables like literacy rate, school enrolment rate, and educational attainment have been used alternatively as proxies for human capital (see, e.g., Romer, 1990a; Barro, 1991; Barro and Lee, 1993). Like physical capital, human capital is a stock, subject to accumulation and perhaps depreciation. Investment in education upgrades worker quality, and the accumulation of knowledge enhances the economy-wide knowledge base, which in turn generates the potential

7. The rate of return on education is defined as the percentage increase in national income for an additional year of education, i.e., $d\mathrm{Ln}Y/dH$.

8. For example, the contribution of capital, labour, and human capital to economic growth is calculated as $\alpha(\dot{K}/K)/(\dot{Y}/Y)$, $\beta(\dot{K}/K)/(\dot{Y}/Y)$, and $\phi H/(\dot{Y}/Y)$, respectively.

9. For theoretical models see, e.g., Stokey (1991b), Young (1991) and Grossman and Helpman (1991); for empirical studies see, e.g., Dollar (1992) and Harrison (1996).

10. In their cross-country study, Gould and Ruffin (1995) noted that in addition to its role as an input in production, the stock of human capital has the greatest responsibility for higher growth in open economies. Edwards (1993) and Harrison (1996) also found that countries that are more open to international trade tended to have higher returns to education.

for new ideas. Hence, in our study human capital is proxied by educational attainment,[11] the average years of education for the employed workers, which is defined as[12]

$$H = \sum_{i=1}^{5} \frac{L_i}{L} S_i$$

where S_i denotes the years of education dedicated to each type of education workers, L_i represents the number of workers which have attained that level/type of education, and L is the total number of the employed workers. Because of the limitation on the early time-series data of educational attainment at the two-digit industrial level, our study of manufacturing industry is confined to the time period 1978–1994 (analysis of the aggregate spans 1964–1994).

Definitions of variables and sources are listed in Appendix A. Table 1 lists the mean values of statistics across the manufacturing industry. For 1978–1994, the average annual growth rates of GDP, labour, and capital are 6.6%, 1.6%, and 6.1%, respectively. The average annual growth rate of GDP is especially high (9 to 10%) for electrical and electronic machinery, machinery, fabricated metals, chemicals, and basic metals. The average educational attainment at the aggregate manufacturing level is 9.2 years, while petroleum, chemicals, tobacco, and electrical and electronic machinery industries are highest among the component subsectors, at between 10 and 11 years. Except for the petroleum and tobacco industries which are state-owned monopolies,[13] chemical and basic metals industries have the highest capital labour ratio and labour productivity. In terms of trade intensity (i.e., the sector-by-sector analogue to the national-level ratio of exports plus imports to GDP), Taiwan's manufacturing industry is substantially open to the international market. The mean value of aggregate manufacturing's total exports plus imports is roughly double that of its total product Among the two-digit industries, rubber and plastic products, precision instruments, machinery and equipment, and electrical and electronic machinery industries have a mean value above three.

11. Note that for Taiwanese data the correlation coefficient between educational attainment and flow variables like school enrolment rate is as high as 0.9.

12. This definition is the same as in Barro and Lee (1993). Eight types of educational attainment are available for Taiwan: illiterate, self-educated, primary school, junior high, senior high, vocational, Junior college, and college and graduate school. As the occupation of illiterate and self-educated is relatively similar to that of workers with primary school education, these three types of workers are treated as one category. Senior high and vocational school are also combined as one category. Hence, five types of educational attainment are included in our calculation.

13. These state-owned enterprises, many of which are also 'natural' monopolies are not only more capital-intensive but also have relatively better educated employees than do other industries because the employees in these industries must pass an entrance examination and certain qualifications are a prerequisite. It is for these reasons that we exclude these two industries in our empirical estimation in Section IV.3.

Table 1 Summary of Statistic Mean Values: 1978–1994

Sector	*Y*	*YL*	*KL*	*H*	*TRD*	*GY*	*GL*	*GK*	*GH*	*GHL*
Manufacturing	1,206,726.240	0.506	0.648	9.171	1.994	0.0661	0.0162	0.0609	0.0114	0.0275
	(397,472.480)	(0.137)	(0.169)	(0.572)	(0.102)	(0.0440)	(0.0388)	(0.0144)	(0.0166)	(0.0420)
Food	102,513.470	0.826	0.807	8.946	1.013	0.0488	0.0066	0.0452	0.0156	0.0223
	(26,202.570)	(0.192)	(0.182)	(0.737)	(0.114)	(0.0467)	(0.0338)	(0.0156)	(0.0522)	(0.0591)
Tobacco	22,406.240	5.313	7.441	10.546	0.261	0.0309	0.0154	0.0226	0.0105	0.0260
	(3,492.640)	(0.519)	(1.205)	(1.221)	(0.162)	(0.0675)	(0.0855)	(0.0416)	(0.0572)	(0.0926)
Textiles	93,079.590	0.360	0.795	8.846	1.530	0.0389	−0.0272	0.0395	0.0140	−0.0132
	(19,553.250)	(0.120)	(0.316)	(0.521)	(0.316)	(0.0787)	(0.0466)	(0.0325)	(0.0436)	(0.0719)
Wearing Apparel	54,095.410	0.451	0.322	8.394	2.799	0.0016	−0.0095	0.0001	0.0098	0.0002
	(10,742.300)	(0.047)	(0.038)	(0.412)	(0.468)	(0.1099)	(0.0761)	(0.0363)	(0.0401)	(0.0749)
Leather Products	17,843.240	0.321	0.239	8.425	2.268	0.0410	0.0061	0.0800	0.0093	0.0154
	(5,707.100)	(0.058)	(0.094)	(0.406)	(0.397)	(0.1313)	(0.0823)	(0.0611)	(0.0469)	(0.0932)
Wood Products	32,898.350	0.261	0.364	7.621	2.152	0.0283	−0.0176	0.0298	0.0159	−0.0017
	(10,144.280)	(0.085)	(0.102)	(0.618)	(0.464)	(0.1504)	(0.0635)	(0.0143)	(0.0464)	(0.0706)
Paper and Printing	51,521.240	0.531	0.771	9.435	0.758	0.0477	0.0401	0.0727	0.0119	0.0520
	(12,632.420)	(0.056)	(0.181)	(0.612)	(0.235)	(0.0955)	(0.0264)	(0.0420)	(0.0427)	(0.0458)
Chemicals	166,016.470	1.472	2.425	10.924	1.510	0.0989	0.0216	0.0616	0.0119	0.0335
	(73,257.580)	(0.528)	(0.650)	(0.680)	(0.239)	(0.0679)	(0.0433)	(0.0337)	(0.0585)	(0.0919)
Petroleum and Coal	108,222.940	7.625	7.284	11.736	0.000	0.0429	0.0399	0.0863	0.0098	0.0498
	(22,134.730)	(0.716)	(2.367)	(0.670)	–	(0.0847)	(0.0402)	(0.0594)	(0.0664)	(0.0833)

Table 1 (Cont'd)

Sector	*Y*	*YL*	*KL*	*H*	*TRD*	*GY*	*GL*	*GK*	*GH*	*GHL*
Rubber and Plastics	16,941.880	0.061	0.077	8.768	8.461	0.0619	0.0055	0.0701	0.0120	0.0175
	(4,863.120)	(0.017)	(0.025)	(0.464)	(1.397)	(0.0836)	(0.0677)	(0.0471)	(0.0474)	(0.0831)
Non-metallic Minerals	50,349.000	0.484	0.845	8.362	0.777	0.0760	0.0114	0.0551	0.0220	0.0334
	(18,389.990)	(0.173)	(0.169)	(0.721)	(0.141)	(0.0466)	(0.0287)	(0.0481)	(0.0393)	(0.0571)
Basic Metals	76,746.180	0.920	2.030	9.281	2.474	0.0939	0.0450	0.0716	0.0126	0.0576
	(34,301.740)	(0.245)	(0.249)	(0.855)	(0.502)	(0.0509)	(0.0402)	(0.0645)	(0.0538)	(0.0586)
Fabricated Metal	61,138.410	0.330	0.493	8.548	1.790	0.0986	0.0616	0.1033	0.0117	0.0733
	(30,986.810)	(0.088)	(0.129)	(0.504)	(0.274)	(0.0873)	(0.0444)	(0.0487)	(0.0213)	(0.0470)
Machinery	46,499.530	0.384	0.486	9.584	4.905	0.0995	0.0388	0.0820	0.0125	0.0512
	(23,435.940)	(0.122)	(0.099)	(0.683)	(1.094)	(0.0778)	(0.0300)	(0.0298)	(0.0413)	(0.0575)
Electrical Machinery	162,074.060	0.381	0.324	10.309	3.236	0.1005	0.0311	0.0840	0.0090	0.0401
	(87,977.800)	(0.156)	(0.087)	(0.527)	(0.330)	(0.1008)	(0.0766)	(0.0307)	(0.0291)	(0.0907)
Transport Equipment	83,988.880	0.673	0.486	9.705	1.716	0.0666	0.0320	0.0438	0.0071	0.0390
	(29,662.270)	(0.156)	(0.045)	(0.521)	(0.177)	(0.0672)	(0.0402)	(0.0335)	(0.0233)	(0.0415)
Precision Instruments	13,506.880	0.412	0.348	9.912	5.183	0.0453	0.0210	0.0720	0.0048	0.0258
	(4,253.640)	(0.063)	(0.092)	(0.436)	(0.536)	(0.0952)	(0.0866)	(0.0328)	(0.0506)	(0.1024)
Misc. Manufactured	46,884.470	0.401	0.179	8.296	2.716	0.0000	0.0145	0.0107	0.0206	0.0351
	(11,136.650)	(0.044)	(0.028)	(0.748)	(0.307)	(0.1078)	(0.0805)	(0.0343)	(0.0509)	(0.0932)

Notes: Standard deviations are in parentheses.
Y: Output in Million NT$ value at 1991 constant price; *YL*: output-labour ratio; *KL*: capital-labour ratio; *G*[*]: growth rate for variable [*].

Ordinary Least Square (OLS) estimation is employed for single equations while both OLS and Seemingly Uncorrelated Regression (SUR) methods are adopted for simultaneous cross-industry estimation.[14]

IV. Results of Estimation

4.1 The whole economy

By using macro level data for the period 1964–1994, we first check for the validity of the model specification given in Equation (3) in Section III. We find that output, labour, physical capital and education variables all exhibit a unit root property and, moreover, they are cointegrated.[15] Therefore, according to Engle and Granger (1987), Equation (3) in Section III actually describes a long-run equilibrium relationship of the variables. The estimated aggregate production function gives

$$\begin{aligned} \text{Ln}Y = &\ 1.1708 + 0.4189\text{Ln}K + 0.5811\text{Ln}L + 0.2475H \\ &(0.1831)\ (0.0973) \qquad (0.0973) \qquad (0.0087) \\ &\qquad\qquad\qquad\qquad N = 31,\ R^2 = 0.9948 \end{aligned} \tag{6}$$

A test of constant returns to scale hypothesis cannot be rejected at the 5% significance level, and the estimated total rate of return to a marginal year of education for the whole economy is approximately 25%.[16] That is, an additional year of education attained will increase national income by 25%. The calculated contribution of each factor to aggregate economic growth is 42%, 20%, and 33% for physical capital, raw labour, and human capital, respectively.[17]

If we separate human capital into embodied and disembodied human capital, we obtain the results

$$\begin{aligned} \text{Ln}Y = &\ 0.5283 + 0.3937\text{Ln}K + 0.6063\text{Ln}HL + 0.1881H \\ &(0.0999)\ (0.1040) \qquad (0.1040) \qquad (0.0389) \\ &\qquad\qquad\qquad\qquad N = 31,\ R^2 = 0.9947 \end{aligned} \tag{7}$$

14. Zellner's seemingly unrelated regressions (SUR) method may improve the efficiency of parameter estimates when there is contemporaneous correlation of errors across equations; theoretically, SUR parameter estimates are invariably at least as efficient as OLS in a large sample provided that the system is well specified. Although system methods are asymptotically most efficient in the absence of specification error, they are more sensitive to specification error than single-equation methods. Therefore, we report the results of the two estimations.

15. See Tables B1 and B2 in Appendix B for the estimation results of unit root and cointegration tests.

16. This estimation result for the rate of return to education is comparable to Psacharopoulos's (1985, 1994) findings of 15–20% for developing countries.

17. For 1964–1994, the average annual growth rate for GDP, capital, labour and education are 8.346%, 8.343%, 2.920%, and 1.326%, respectively. The mean duration of education is 8.47 years. See also footnote 7 for the calculation.

The estimated purely external effect of education is roughly 19%. Thus the private rate of return to education, the difference between 25% and 19%, equals 6% in the aggregate level. The calculated contribution to aggregate economic growth is 39%, 31%, and 25% for physical capital, effective labour, and disembodied human capital, respectively. Hence, broadly defined (embodied plus disembodied) human capital accounts for 56% of Taiwan's aggregate economic growth. Moreover, the estimated labour and capital shares in Equations (6) and (7) are close to those found in the national income account and the inclusion of human capital along with physical capital and raw labour explain approximately 96% of economic growth. The unexplained Solow residual trend is reduced to less than 5% of observed growth during this period! Therefore, the inclusion of human capital externality as in Equation (3) in Section III appears to be a better model specification and more accurate representation of the role of human capital.

However, using macro data to estimate an aggregate production function cannot accurately reflect the underlying industrial structure and characteristics of industries. In particular, in the transition of Taiwan's economy from an agriculturally oriented to an industrially oriented one, the role of human capital has arguably been most decisive in the rising industrial sector, and more specifically, in a few subsectors. Thus, this paper goes one step further and concentrates on manufacturing industry, first at the aggregate level in Section IV.2. Finally, in Section IV.3, use of industry-level data allows the external effect of human capital to be further decomposed into intra-industry and inter-industry effects, as formulated in Equation (5) of Section III.

IV.2 Aggregate manufacturing industry

Table 2 summarizes the regression results for aggregate manufacturing industry. From column (1) the estimated output elasticity of raw labour is 0.27; the test of constant returns' hypothesis cannot be rejected and a positive time trend exists. Using the formulation in Equation (3), where education appears as embodied human capital, from column (2) the estimated output elasticity of effective labour is 0.33. However, a positive time trend cannot be rejected either. Since such a trend might actually mask a knowledge spillover, we next insert into columns (3) and (4) a variable for average years of education in the manufacturing industry to capture this external effect. We do, in fact, find a positive and significant and significant external effect (0.2892, s.e. = 0.0515 in column (3) and 0.2245, s.e. = 0.0389 in column (4)). Therefore, the total rate of return to education is estimated to be about 29% and the knowledge spillover effect is 22%. The difference of 7% can, thus, be taken as a private return on education for the manufacturing sector (compared with 6% obtained for the whole economy).[18]

18. This figure is consistent with the findings in Psacharopoulus (1994) that the average private rates of return for one additional year of education for Taiwan and the upper middle income countries are 6.0% and 7.8%, respectively.

Table 2 Regression Results for Aggregate Manufacturing Industry

	LnY (1)	LnY (2)	LnY (3)	LnY (4)	LnY (5)	LnY (6)	LnY (7)	LnY (8)
Constant	−0.6082	−1.3427	−3.172	−3.8522	−0.5221	−0.3185	−0.4750	−0.9617
	(−7.2751)	(−5.0496)	(−6.0385)	(−5.8965)	(−1.3586)+	(−0.8630)+	(−4.0251)	(−6.9486)
Trend	0.1188	0.1104						
	(4.7520)	(5.3077)						
LnK	0.7338	0.6735	0.4196	0.4239	1.0809	1.0584	0.9257	0.8053
	(9.1155)	(7.7414)	(3.5113)	(3.6107)	(13.0229)	(9.5438)	(32.2530)	(18.1374)
LnL	0.2662		0.5804		−0.0809		0.0743	
	(3.3068)		(4.8569)		(−0.9747)+		(2.5902)	
LnHL		0.3265		0.5761		−0.0584		0.1947
		(3.7529)		(4.9072)		(−0.5267)+		(4.3851)
H			0.2892	0.2245				
			(5.6155)	(5.7712)				
TRD					0.1551	0.1126	−4.4708	−3.8836
					(0.7701)+	(0.5442)+	(−11.1241)	(−10.0559)
LABTRD							0.3114	
							(11.6647)	
HLTRD								0.2358
								(10.5266)
N	17	17	17	17	17	17	17	17
D-W	0.818	0.932	2.317	2.327	0.374	0.362	1.798	1.943
Adj R-sq	0.9839	0.9858	0.9871	0.9873	0.9598	0.9579	0.9962	0.9952

Notes: t value in the parentheses. All the estimated coefficients are significant at the 1% level except those suffixed +.
D-W is the Durbin-Watson test statistic.

Notably, the external effect is approximately three times that of the private return to education. After explicitly allowing for knowledge spillover, the output elasticity of raw labour becomes 0.58, which is empirically close to the income share of labour in Taiwan, and the unexplained time trend capturing exogenous technical change has become insignificant (the result is not shown in the Table). Hence, using data for aggregate manufacturing, as in the economy-wide macro level comparison of the results of columns (1) and (2) to those from columns (3) and (4), reveals that including the productivity effect of human capital into the production function is a more appropriate specification. Regression performance is significantly improved, and estimated parameters align closely to the relevant figures obtained in national income accounts.

Following upon numerous investigations of the effects of trade on a country's production efficiency and thus a its economic growth (see, e.g., Michaely, 1977; Kreuger, 1984; Harberger, 1984; Dollar, 1992; Harrison, 1996), we next insert trade intensity (imports plus exports as a share of GDP) into columns (5) and (6). At this first pass, trade appears to have a negative and insignificant effect on growth. However, as noted in the introduction, trade is likely to interact with the accumulation of human capital. In several recently proposed endogenous growth models with constant returns learning spillover technology,[19] learning enables a country to produce new goods and shifts the production spectrum toward more refined goods, thereby stimulating local accumulation of human capital. To verify such a proposal, in columns (7) and (8), we further add an interaction term between trade and labour and/or human capital. The estimated coefficients of the trade variable are negative and significant, however, the interaction terms are positive and significant (e.g., –3.8836, s.e. = 0.3862 for the trade variable and 0.2358, s.e. = 0.0224 for the interaction term in column (8)). These results imply that trade and human capital are complementary to economic growth.[20] Therefore, opening trade may not be beneficial to economic growth; instead, a threshold of human capital exists for trade to have positive effect on output. The estimated thresholds (at which the interaction term exactly offsets the negative direct effect) for the logarithmic values of effective labour and raw labour are 16.47 and 14.36, respectively; hence, the calculated minimum years of education is 8.25 years. Our sample mean values for logarithmic effective labour, logarithmic raw labour, and education all exceed the required thresholds and have the values of 16.90, 14.68 and 9.17, respectively.[21] The minimum requirement of

19. See, for example, Stokey (1991b), Young (1991), and Chuang (1998). Stokey (1991b) and Young (1991) suggested that on opening trade the advanced country grows faster at the expense of the poor country and the accumulation of human capital in the poor country is discouraged. However, Chuang (1998) demonstrated that the trade-induced learning spillover effect from the advanced country to the poor country can actually help the poor country grow faster and continuously shift its production spectrum in an upward direction.

20. See Lucas (1990) and Levin and Raut (1992) for this line of argument.

21. From Table 1, the mean value of raw labour is 2,384,834 persons. Note that in 1968 a nine-year mandatory educational reform was implemented in Taiwan.

8.25 years of education corresponds to widespread evidence of a significant and positive effect of secondary education on long-run growth in cross-country regressions (see, e.g., Barro, 1991).

IV.3 Two-digit industry

Analysis at the two-digit industry level, allows the external effect of human capital to be further decomposed into intra- and inter-industry effects. Moreover, it also allows parameter heterogeneity across industries, reflecting divergent characteristics held by the industries. First, we conduct the benchmark estimation, i.e., the constrained model, in which all the coefficients are restricted to be homogenous across industries except the constant term reflecting the industry-specific effect. Second, we run the unconstrained model by relaxing homogeneity restrictions on some of the coefficients; for example, the effect of education, trade and their interaction terms.

IV.3.1 The constrained model

Under the constrained model, technology is assumed to be comparable across two-digit industries; the effects (internal and external) of education are thus also the same across industries.[22] In addition to the external effect of own-industry education (i.e., the intra-industry effect), we further consider the variable of average years of education in the manufacturing sector as a whole (MFGH) to capture the second, inter-industry, external effect as formulated in Equation (5) of Section III. Comparing the fourth columns of Tables 3 and 4, we find that the estimated intra-industry external effect of education is zero for OLS and 3% for SUR, while the inter-industry external effect is about 23% for OLS and 17% for SUR. Therefore, the total (intra- plus inter-industry) external rate of return to education at the two-digit industry level is about 20–23%, which is close to our estimation of 22% in the aggregate manufacturing level. However, disaggregated results additionally provide strong evidence that most of the externality comes from *inter*-industry knowledge spillover.

Furthermore, from column (3) of Tables 3 and 4, the estimated internal (own-industry, embodied plus disembodied) rate of return to education is 8% for both cases of OLS and SUR, while the inter-industry external rate of return to education is 17–23%. *It is notable that the inter-industry effect of education is two to three times the magnitude of the intra-industry effect. Hence, neglecting the external effect of education severely underestimates the actual rate of return for education, and, moreover, misrepresents the technological progress stemming from knowledge spillovers.*

As in the aggregate manufacturing level adding the trade variable and interaction term between trade and human capital, we find a negative coefficient for the

22. However, we still allow for different constant terms for each of the two-digit industries reflecting their industry-specific characteristics.

Table 3 Results for Two-digit Industries
The Constrained Model: OLS estimation

	Ln*Y* (1)	Ln*Y* (2)	Ln*Y* (3)	Ln*Y* (4)	Ln*Y* (5)	Ln*Y* (6)	Ln*Y* (7)	Ln*Y* (8)	Ln*Y* (9)	Ln*Y* (10)
Ln*K*	0.5177	0.4957	0.2706	0.2661	0.6348	0.6811	0.6288	0.6875	0.3089	0.4894
	(17.9666)	(14.7343)	(9.3597)	(9.2149)	(29.6974)	(32.8743)	(30.5147)	(32.9528)	(12.3160)	(19.3452)
Ln*L*	0.4823		0.7294		0.3652		0.3712		0.6911	
	(16.7363)		(25.2340)		(17.0862)		(18.0125)		(27.5564)	
Ln*HL*		0.5043		0.7339		0.3189		0.3125		0.5106
		(14.9922)		(25.4132)		(15.3953)		(14.9789)		(20.1805)
H			0.0785	−0.0043	0.1375		0.1385		0.0542	
			(6.6483)	(−0.3496)+	(12.3277)		(13.3818)		(4.5193)	
MFGH			0.2270	0.2292					0.2389	0.1556
			(13.1566)	(13.3599)					(16.1524)	(15.1075)
TRD					−0.1210	−1.2510	−0.1402	−1.2208	−0.1188	−0.7134
					(−4.0281)	(−18.2733)	(−5.2016)	(−19.7535)	(−4.4998)	(−9.9359)
MFGTRD							0.1902	0.1346	0.2204	0.2485
							(4.7294)	(3.1302)	(5.7037)	(5.8473)
HTRD					0.0070		0.0076		0.0055	
					(2.0120)*		(2.3781)**		(1.7881)+	
HLTRD						0.0821		0.0804		0.0451
						(17.2864)		(18.4221)		(9.0180)

Notes: *t* value in the parentheses. All the estimated coefficients are significant at the 1% level, except that ** and * show for significance at the 5% and 10% levels, respectively, and + insgnificance.

Table 4 Results for Two-digit Industries
The Constrained Model: SUR estimation

	Ln*Y* (1)	Ln*Y* (2)	Ln*Y* (3)	Ln*Y* (4)	Ln*Y* (5)	Ln*Y* (6)	Ln*Y* (7)	Ln*Y* (8)	Ln*Y* (9)	Ln*Y* (10)
Ln*K*	1.1530	0.2586	0.5758	0.6557	0.4748	0.4428	0.5620	0.4028	0.3185	0.8556
	(189.0164)	(68.0526)	(54.6585)	(65.5394)	(135.5344)	(70.0288)	(76.6233)	(41.8383)	(28.0782)	(55.3719)
Ln*L*	−0.1530		0.4242		0.5252		0.4380		0.6815	
	(−25.0820)		(40.2632)		(149.9352)		(59.7280)		(60.0897)	
Ln*HL*		0.7414		0.3443		0.5572		0.5972		0.1444
		(195.1053)		(34.4106)		(88.1240)		(62.0254)		(9.3447)
H			0.0847	0.0319	−0.0880		0.1430		−0.0585	
			(30.6551)	(11.8438)	(−43.1644)		(41.3246)		(−12.2423)	
MFGH			0.1782	0.1714					0.2228	0.0795
			(28.4708)	(29.5639)					(33.8655)	(12.4801)
TRD					−0.2403	−0.3092	0.0329	−0.3112	−0.2380	−0.0481
					(−59.9706)	(−19.4898)	(4.7140)	(−16.1705)	(−20.3608)	(1.8581)*
MFGTRD							0.8727	0.9141	0.1699	0.7805
							(73.6082)	(46.6282)	(7.6180)	(25.6215)
HTRD					0.0250		−0.0166		0.0211	
					(51.5267)		(−21.3111)		(15.3174)	
HLTRD						0.0163		0.0128		−0.0015
						(14.7918)		(9.1429)		(−0.8561)+

Notes: Equations (1) and (2) are with time trend.
See notes to Table 3.

trade variable and a positive coefficient for the interaction term (see columns (5) and (6) in Tables 3 and 4). A minimum education requirement for a positive trade effect is again confirmed. The estimated positive and significant coefficient for the interaction term implies that trade increases the rate of return on education. For Taiwan's economy, which shifted from a closed regime to an open one with an average value of two measured by trade intensity, rough extrapolation suggests the rate of return to education has increased by approximately 1.4%. Also using data on Taiwan's two-digit industries, Chuang (1996) found that trade-induced learning effect accounts for about 50% to 75% of the external effects.

By considering both externalities of education and trade from aggregate manufacturing level (MFGH and MFGTRD) to each of two-digit industries, columns (7)–(10) in Tables 3 and 4 reveal that estimated coefficients of both MFGH and MFGTRD variables are positive and significant. This finding implies that both education and trade have an inter-industry external effect among the two-digit industries. In column (9) of Table 3, the magnitudes of both coefficients are roughly the same about 0.22. That is, the spillover effect of an additional year of education on labour is approximately equal to that of a doubling the degree of trade openness.

IV.3.2 The unconstrained model

In this section, based on the models in columns (3) and (9) of Tables 3 and 4, we further relax the assumptions and allow for differences in rates of return to education, the effects of trade, and its interaction with education among these two-digit industries. Tables 5, 6 and 7 summarize these results. In Table 5, own-industry returns to education are seen to vary markedly across industries, and sets of estimates for OLS and SUR show large discrepancies. For OLS estimation, the range is between –0.110 for leather and fur products to 0.3276 for electrical and electronic machinery industry. In addition to the latter, most chemicals and chemical products, textiles, machinery, and non-metallic minerals industries also have rates of returns for education of over 20%. For SUR estimation, the range is between –0.6269 for wood industry to 0.1343 for basic metals industry; while basic metals, non-metallic minerals, and precision instrument industries all have rates of return above 10%. Finally, the common inter-industry external effect of education is 0.1505 for OLS and 0.2269 for SUR.

As for the inclusion of trade and its interaction with education, Tables 6 and 7 reveal different threshold or ceiling effects existed among industries. Following Borensztein, De-Gregorio and Lee (1995), a threshold effect is identified when a negative own effect coexists with a positive effect on the interaction term. Thus, the threshold characteristics of knowledge stock for generating a net positive trade effect are verified for textiles, wearing apparel, leather products, wood products, non-metallic minerals, electrical and electronic machinery, and transport equipment industries. The positive effect of interaction terms for these industries also implies that trade increases the rate of return on education. In contrast, however, a ceiling effect is confirmed when a positive own effect

Table 5 Variable Own-Industry Returns of Education in Two-digit Industries
The Unconstrained Model

Sector	OLS H	SUR H
Food	0.0587	0.0346
	(3.5566)	(5.2792)
Textiles	0.2317	0.0574
	(5.2474)	(2.3063)**
Wearing Apparel	−0.1083	−0.2017
	(−2.1880)**	(−7.4563)
Leather Products	−0.1105	−0.1626
	(3.2396)	(−12.8111)
Wood Products	0.1686	−0.6269
	(4.2711)	(−25.5883)
Chemicals	0.2659	0.0733
	(4.8470)	(3.6956)
Rubber and Plastics	0.0944	−0.0345
	(2.0340)*	(−1.8052)*
Non-metal. Minerals	0.2144	0.1060
	(10.4175)	(16.2126)
Basic Metals	0.1321	0.1343
	(5.2289)	(10.0931)
Fabricated Metal	0.1236	−0.4199
	(3.3987)	(−24.7426)
Machinery	0.2149	–
	(10.3539)	
Electrical Machinery	0.3276	−0.0067
	(8.6079)	(−0.3156)+
Transport Equipment	0.1459	0.0130
	(3.8938)	(0.5814)+
Precision Instruments	−0.0466	0.0935
	(−0.7003)+	(5.3655)
Misc. Manufactured	−0.1429	−0.1939
	(−4.1663)	(−11.2081)

Notes: The estimated constrained parameters for Ln*L*, Ln*K*, and *MFGH* are 0.3558, 0.6642, and 0.1505 for OLS; and 0.7675, 0.2325, and 0.2269 for SUR. All the estimates are significant at the 1% level.
See notes to Table 3.

coexists with a negative interaction effect. Thus, rubber and plastic products and machinery industries are characterized by a ceiling rather than a threshold effect for education and the negative coefficient on interaction terms, suggesting a substitution effect between trade and education for these two industries. For the rubber and plastic products industry, the lower requirement for education level may be partly due to the labour-intensive property of the industry.[23]

23. The sample mean value of the capital-labour ratio for the rubber and plastic products industry is 0.077, i.e. the smallest among the two-digit industries.

Table 6 Variable Own-Industry Effects of Education and Trade for Two-digit Industries The Unconstrained Model: OLS Estimation

Sector	*H*	*TRD*	*HTRD*
Food	−0.2241	−2.7586	0.2723
	(−1.7769)+	(−2.5019)**	(2.0719)*
Textiles	0.5109	0.9739	−0.1228
	(4.8151)**	(0.8508)+	(−1.0083)+
Wearing Apparel	−0.7233	−1.8013	0.2035
	(−2.5812)**	(−2.3099)**	(2.1309)*
Leather Products	−0.6003	−1.9670	0.2528
	(−3.1167)**	(−2.4588)**	(2.6467)**
Wood Products	−0.2571	−1.1410	0.0915
	(−1.1736)+	(−1.3478)+	(0.8007)+
Chemicals	0.2923	0.2486	−0.0942
	(1.0981)+	(0.1497)+	(−0.6072)+
Rubber and Plastics	0.8319	0.8095	−0.0979
	(3.0216)**	(2.6991)**	(−2.8552)**
Non-metal. Minerals	−0.4067	−8.8971	0.9968
	(−2.3454)**	(−3.8797)**	(3.6992)
Basic Metals	0.1608	−0.0976	−0.0010
	(1.2456)+	(−0.2087)+	(−0.0213)+
Fabricated Metal	0.0803	0.1561	−0.0654
	(0.2511)+	(0.1017)+	(−0.3714)+
Machinery	0.3663	0.3210	−0.0415
	(4.4117)	(2.0721)*	(−2.5148)**
Electrical Machinery	−0.6400	−3.6903	0.3247
	(−1.4926)+	(−2.5373)**	(2.3613)**
Transport Equipment	−0.4876	−3.8160	0.3986
	(−0.9814)+	(−1.3818)+	(1.3995)+
Precision Instruments	0.6409	0.9974	−0.1171
	(0.7139)+	(0.5960)+	(−0.6835)+
Misc. Manufactured	−0.2192	−0.6338	0.0668
	(−1.3473)+	(−1.3443)+	(1.1017)+

Notes: The estimated constrained parameters for Ln*L*, Ln*K*, *MFGH*, and *MFGTRD* are 0.6830, 0.3710, 0.1731 and 0.2357. All the estimates are significant at the 1% level.
See notes to Table 3.

Table 8 summarizes the required threshold of education for these industries. Comparing sample mean values to estimates in Table 8, we find that the textile, wearing apparel, leather products, and transport equipment industries satisfy the minimum required level for education, and that neither rubber and plastic products nor machinery industries exceed the estimated ceiling level. In other words the net effect of trade remains positive. In fact, all these industries are relatively outward-oriented, as reflected by trade intensities above the mean value of aggregate manufacturing. Finally, it is noteworthy that even after allowing

Table 7 Variable Own-Industry Effects of Education and Trade for Two-digit Industries The Unconstrained Model: SUR Estimation

Sector	*H*	*TRD*	*HTRD*
Food	0.2217	1.1407	−0.2050
	(2.3865)**	(1.4003)+	(−2.1584)*
Textiles	−0.4295	−3.3531	0.3588
	(−5.7043)	(−8.1817)	(8.3126)
Wearing Apparel	−0.8486	−1.8393	0.1933
	(−7.8070)	(−5.9238)	(5.1952)
Leather Products	−0.4964	−1.5322	0.1960
	(−8.0310)	(−6.0487)	(6.4913)
Wood Products	−0.5477	−1.9498	0.2210
	(−4.2301)	(−3.9049)	(3.2667)
Chemicals	−0.1397	−2.6511	0.1360
	(−1.1216)+	(−3.3261)	(1.8202)+
Rubber and Plastics	0.3872	0.5536	−0.0665
	(2.8304)**	(3.8101)	(−3.9866)
Non-metallic Minerals	0.2963	1.4393	−0.1867
	(4.1528)	(1.4914)+	(−1.6475)+
Machinery	0.4137	0.5324	−0.0640
	(8.0874)	(5.6387)	(−6.2620)
Electrical Machinery	0.0681	−1.2095	0.0898
	(0.2887)+	(−1.5254)+	(1.2004)+
Transport Equipment	−1.1611	−5.3494	0.6098
	(−6.3636)	(−5.3358)	(5.8313)
Precision Instruments	−1.2455	−2.9866	0.3009
	(−1.8902)*	(−2.4493)**	(2.3960)**
Misc. Manufactured	−0.3138	−0.4599	0.0626
	(−4.5877)	(−2.1860)*	(2.4546)**

Notes: The estimated constrained parameters for Ln*L*, Ln*K*, *MFGH*, and *MFGTRD* are 0.5390, 0.4610, 0.1118 and 0.2254. All the estimates are significant at the 1% level.
See notes to Table 3.

for heterogeneity effects of education and trade, the common inter-industry external effects of education and trade remain positive and significant (MFGH: 0.1731 for OLS and 0.1118 for SUR; MFGTRD: 0.2357 for OLS and 0.2254 for SUR).

Overall, opening trade and the accumulation of human capital have simultaneously played important roles in Taiwan's development, and moreover have been mutually reinforcing. Open trade stimulates the processes of human capital accumulation, and the accumulation of human capital helps to strengthen technological capabilities to absorb the potential benefits (e.g., technology adoption, transfer and diffusion) from opening trade. Moreover, there exist significant and positive external spillover effects for both education and trade.

Table 8 The Calculated Threshold and Ceiling for Education and Trade

	OLS		SUR		Sample Mean	
Sector	*H*	*TRD*	*H*	*TRD*	*H*	*TRD*
Minimum Threshold						
Textiles	–	–	8.717	0.885	8.846 (0.521)	1.530 (0.316)
Wearing Apparel	–	–	8.351	3.813	8.394 (0.412)	2.799 (0.468)
Leather Products	6.850	1.690	6.668	1.962	8.425 (0.406)	2.268 (0.397)
Wood Products	–	–	7.802	1.972	7.621 (0.618)	2.152 (0.464)
Non-metallic Minerals	8.689	0.234	–	–	8.362 (0.721)	0.777 (0.141)
Electrical Machinery	10.640	1.438	–	–	10.309 (0.527)	3.236 (0.330)
Transport Equipment	–	–	8.402	1.721	9.705 (0.521)	1.716 (0.177)
Maximum Ceiling						
Rubber and Plastics	10.672	10.262	11.714	7.504	8.768 (0.464)	8.461 (1.397)
Machinery	13.416	13.000	11.836	8.208	9.584 (0.683)	4.905 (1.094)

Notes: – denotes the estimate is statistically insignificant.
The inter-industry effects of trade and education are included in calculating the threshold values.
Numbers in parentheses are standard deviations.

IV.4 Contribution of human capital on economic growth

Table 9 summarizes the relative contributions of each factor to economic growth. From 1978 to 1994, for the entire manufacturing industry, raw labour and physical capital contribute about 7% and 68%, respectively. Measured in terms of effective labour and physical capital, the corresponding estimates are 14% and 62%. Therefore, the contribution of embodied education is about 7%. However, one-fourth of output growth is still left unaccounted for. When we include disembodied human capital and inter-industry knowledge spillovers in the specification (see columns (5) to (8)), we note that the total contribution of education is 46%. Differencing these two estimates, we thus find that the *external* effect of education on productivity contributed 39% of manufacturing's output growth. Moreover, under this specification, the contributions of raw labour, physical capital and human capital are 14.20%, 38.68%, and 45.68%, respectively, accounting for 98.53% of the total output growth. In other words, the unexplained Solow

Table 9 Contribution to Economic Growth

Sector	(1) *L*	(2) *K*	(3) *HL*	(4) *K*	(5) *L*	(6) *K*	(7) *H*	(8) *MFGH*	(9) *EMBH*	(10) *INTRAH*	(11) *INTERH*	(12) TOTAL
Manufacturing	6.51%	67.64%	13.61%	62.08%	14.20%	38.68%	45.65%	–	7.10%	38.55%	–	45.65%
Food	6.58%	47.99%	23.05%	45.95%	9.95%	25.08%	22.52%	48.54%	16.47%	6.05%	26.02%	48.54%
Textiles	–33.67%	52.54%	–17.05%	50.31%	–50.93%	27.46%	25.01%	60.77%	16.62%	8.38%	35.76%	60.77%
Apparel	–9.53%	5.58%	0.55%	5.34%	–14.41%	2.92%	29.06%	106.79%	10.08%	18.98%	77.73%	106.79%
Leather Products	7.16%	101.08%	18.94%	96.78%	10.82%	52.83%	15.02%	57.73%	11.78%	3.24%	42.71%	57.73%
Wood Products	–30.01%	54.64%	–2.99%	52.32%	–45.39%	28.56%	33.68%	83.72%	27.02%	6.66%	50.04%	83.72%
Paper & Printing	40.52%	78.93%	54.94%	75.57%	61.28%	41.26%	18.47%	49.62%	14.42%	4.04%	31.15%	49.62%
Chemicals	10.52%	32.26%	17.06%	30.89%	15.91%	16.86%	10.31%	23.93%	6.55%	3.77%	13.61%	23.93%
Rubber & Plastics	4.28%	58.65%	14.25%	56.16%	6.47%	30.66%	13.34%	38.26%	9.97%	3.37%	24.92%	38.26%
Non-metal. Minerals	7.22%	37.51%	22.18%	35.92%	10.92%	19.61%	19.05%	31.15%	14.96%	4.08%	12.10%	31.15%
Basic Metals	23.11%	39.46%	30.94%	37.78%	34.94%	20.63%	9.79%	25.21%	7.83%	1.96%	15.42%	25.21%
Fabricated Metal	30.15%	54.20%	37.49%	51.90%	45.59%	28.33%	7.94%	24.00%	7.34%	0.60%	16.07%	24.00%
Machinery	18.80%	42.68%	25.97%	40.87%	28.43%	22.31%	9.42%	23.80%	7.17%	2.25%	14.38%	23.80%
Electrical Machinery	14.94%	43.27%	20.12%	41.43%	22.59%	22.62%	7.22%	23.55%	5.18%	2.04%	16.33%	23.55%
Transport Equipment	23.16%	34.03%	29.56%	32.58%	35.02%	17.79%	8.08%	35.54%	6.41%	1.68%	27.46%	35.54%
Precision Instruments	22.33%	82.25%	28.69%	78.75%	33.77%	42.99%	8.24%	52.20%	6.36%	1.88%	43.96%	52.20%

Notes: Calculations of contribution at two-digit industry level are based on the estimates of the constrained model in Table 3.
Contribution of embodied human capital (*EMBH*): (9) = (3) – (1).
Contribution of intra-industry effect of education (*INTRAH*): (10) = (7) – (9).
Contribution of inter-industry effect of human capital (*INTERH*): (11) = (8) – (7).
Total contribution of Human capital (TOTAL): (12) = (9) + (10) + (11).

residual is virtually eliminated when we explicitly include disembodied human capital and inter-industry spillovers!

For two-digit industry estimates, using OLS estimates of the constrained model, contributions of human capital range from 7% to 33%. The contribution appears to have been largest in wood products, textile products, food and nonmetallic mineral products, exceeding 20% of growth in all these industries. Furthermore, within each industry the magnitudes of embodied human capital are more than double those of disembodied human capital. The former lies in 5–27% range, while the latter range is 1–10%. More noteworthy, however, are the significant knowledge spillover effects across industries. The contribution of inter-industry knowledge spillover to observed growth is estimated at between 12 and 50%, exceeding 20% in wood products, precision instruments, leather products, paper products, textile products and transport equipment. The contribution of human capital including embodied, disembodied, and external spillover is generally from 23 to 84%, of which, the lion's share is attributable to inter-industry knowledge spillovers at the two-digit industries level.

V. Concluding Remarks

Using Taiwan's industry data to examine the two potentially important roles – factor accumulation and technology progress – of human capital on long-run economic growth, we find that human capital accounts for 46% of output growth in aggregate manufacturing industry and from 23 to 84% of that in two-digit industries. Significant knowledge spillover effects were found within Taiwan's manufacturing industry. For aggregate manufacturing, the total rate of return on education is about 29%, within which the private return is 7% while the external knowledge spillover effect is 22%. For the two-digit industries, the inter-industry effect of education is two to three times as large as the intra-industry effect of education. Contrary to the Lau-Young proposition, we estimate that technology change – which we further demonstrate to be of the knowledge spillover type – has contributed a 39% share of output growth of Taiwan's aggregate manufacturing and from 12 to 42% for respective two-digit industries. Our results also suggest that, in the presence of externalities, growth accounting based on macro data may be misleading in interpreting the sources of growth.

In addition, Taiwan's case study suggests that opening trade broadens opportunities, and hence increases the return on human capital investment. For Taiwan's economy, which moved from a closed regime to an open one with an average trade intensity ratio of two, the estimated increase in the rate of return to education by opening trade was approximately 1.4% at the two-digit industry level. However, our estimation results also suggests that, in terms of capturing the growth benefits from trade, threshold levels of human capital exist in most industries.

In drawing policy implications from Taiwan's experience, the following elements are critical for enabling developing countries to attain sustained economic growth:

(a) As the external return on education is prominent and a large stock of human capital enhances the capabilities of absorbing and digesting new technology, government should play an aggressive role of promoting investment in human capital throughout the development process. Expansion of mandatory education to nine or more years thus appears justified as an early policy measure.

(b) Trade is conducive to knowledge spillover and technological learning, thereby raising the return on human capital investment. Thus, an outward-oriented trade policy with import liberalization may help a country's economic growth, primarily through a 'virtuous cycle' of accelerating human capital accumulation and intensification of local technological capabilities.

Appendix A

Definitions and Sources of Variables

Ln*Y*	logarithm form of real gross domestic products at 1991 constant price.
Ln*K*	logarithm form of net capital stock at 1991 constant price.
Ln*L*	logarithm form of workers employed.
Ln*HL*	logarithm form of employed workers multiplied by years of education attained (measure of embodied human capital or effective labour).
H	average years of education for employed workers.
MFGH	average years of education for employed workers at aggregate manufacturing level.
TRD	share of exports plus imports to gross domestic product.
MFGTRD	share of exports plus imports to gross domestic product at aggregate manufacturing industry level.
LABTRD	product of Ln*L* and *TRD*.
HLTRD	product of Ln*HL* and *TRD*.
HTRD	product of *H* and *TRD*.

Sources: Ln*Y*: computed from National Income, Taiwan Area, Republic of China, Directorate-Generate of Budget, Accounting, and statistics (DGBAS), 1995.
Ln*L*: computed from Yearbook of Labor Statistics, Taiwan Area, Republic of China, 1995.
Ln*K*: computed from The Trends in Multifactor Productivity of Industrial Sector, Taiwan Area, Republic of China, DGBAS, 1995.
H: computed from manpower survey by DGBAS.
TRD: computed from Monthly Statistics of Exports and Imports, Taiwan Area, Republic of China, Department of Statistics, Ministry of Finance.

Appendix B

Table B1 The Results of the Unit Root Tests

	Augmented Dickey-Fuller	Phillips-Perron	AIC Lags
Levels			
LnY	−1.4620	−4.1081	2
LnL	−0.0370	0.3787	2
LnK	−1.2174	1.2068	2
H	−2.3189	−4.3794	2
First Differences			
LnY	−3.7752**	−16.6793**	2
LnL	−4.2358**	−15.8973**	2
LnK	−4.1686**	−8.1445	2
H	−2.7194*	−38.8020**	2

Notes: Optimal lags are determined by Akaike's information criterion.
* and ** indicate statistical significance at the 5% and 1% levels, respectively.
Sources: See Dickey and Fuller (1979) for ADF test and Phillips and Perron (1988) for PP test.

Table B2 The Results of Johansen's Cointegration Trace Test

Null	Alternative	Statistics	95% Critical value	Eigenvalues
$r = 0$	$r \geq 1$	97.8310*	53.1160	0.75261
$r \leq 1$	$r = 2$	58.7206*	34.9100	0.66045
$r \leq 2$	$r = 3$	28.4765*	19.9640	0.55647
$r \leq 3$	$r = 4$	5.7126	9.2430	0.18456

Notes: Maximum lag in VAR is 2.
* indicates statistical significance at the 5% level.
Sources: See Johansen (1991) and Johansen and Juselius (1990) for maximum likelihood estimation procedure for cointegration test.

References

Barro, Robert J., 1991, Economic growth in a cross section of countries. *Quarterly Journal of Economics*, **106**, pp. 407–443.

Barro, Robert J. and Jong-wha Lee, 1993, International comparisons of educational attainment. *Journal of Monetary Economics*, **32**, pp. 363–394.

Becker, Gary S., Kevin M. Murphy and Robert Tamura, 1990, Capital, fertility, and economic growth. *Journal of Political Economy*, **98**, pp. S12–S37.

Benhabib, Jess and Mark M. Spiegel, 1994, The role of human capital in economic development: evidence from aggregate cross-country data. *Journal of Monetary Economics*, **34**, pp. 143–173.

Borensztein, Eduardo, Jose De-Gregorio and Jong-Wha Lee, 1995, *How Does Foreign Direct Investment Affect Economic Growth*? NBER Working Paper, No. 5057.

Chuang, Yih-chyi, 1998, Learning by doing, the technology gap, and growth. *International Economic Review*, **39**, pp. 697–721.

Chuang, Yih-chyi, 1996, Identifying the sources of growth in Taiwan's manufacturing industry. *Journal of Development Studies*, **32**, pp. 445–463.

Council for Economic Planning and Development, Taiwan, Republic of China, 1998, *Taiwan Statistical Data Book*.

Dickey, D. A. and W. A. Fuller, 1979, Distribution of the estimates for autoregressive time series with a unit root. *Journal of the American Statistical Association*, **74**, pp. 427–431.

Dollar, David, 1992, Outward-oriented developing economies really do grow more rapidly: evidence from 95 LDCs, 1976–1985. *Economic Development and Cultural Change*, **40**, pp. 523–544.

Edwards, Sebastian, 1993, Openness, trade liberalization, and growth in developing countries. *Journal of Economic Literature*, **31,** pp. 1358–1393.

Engle, R. F. and C. W. Granger, 1987, Co-integration and error correction: representation, estimation, and testing. *Econometrica*, **55**, pp. 251–276.

Gould, David M. and Roy J. Ruffin, 1995, Human capital, trade, and economic growth. *Weltwirtschaftliches Archiv*, **131**, pp. 425–445.

Grossman, Gene M. and Elhanan Helpman, 1991, *Innovation and Growth in the Global Economy*. MIT Press, Cambridge, MA.

Gundlach, Erich, 1997, Human capital and economic development: a macroeconomic assessment. *Intereconomics*, (January/February) pp. 23–35.

Harberger, Arnold C., 1984, *World Economic Growth*. ICS Press, San Francisco.

Harrison, Ann, 1996, Openness and growth: a times-series, cross-country analysis for developing countries. *Journal of Development Economics*, **48**, pp. 419–447.

Johansen, S., 1991, Estimation and hypothesis testing of cointegration vectors in gaussian vector autoregressive models. *Econometrica*, **59,** pp. 1551–1580.

Johansen, S. and K. Juselius, 1990, The full information maximum likelihood procedure for inference on cointegration: with application to the demand for money. *Oxford Bulletin of Economics and Statistics*, **52**, pp. 169–210.

Krueger, Anne O., 1984, The developing countries' role in the world economy. In J. A. Frankel and M. L. Mussa, Eds, *The World Economic System: Performance and Prospects*. Auburn House, Dover, MA.

Lau, Lawrence J., Deann T. Jamison, Shu-Cheng Liu and Steven Rivkin, 1993, Education and economic growth: some cross-sectional evidence from Brazil. *Journal of Development Economics*, **41**, pp. 45–70.

Lau, Lawrence J. and Jong-II Kim, 1992, *The Sources of Economic Growth of the Newly Industrializing Countries on the Pacific Rim*. Center for Economic Policy Research Publication, No. 295, Stanford University.

Levin, Andrew and Lakshmi K. Raut, 1992, *Complementarities between Exports and Human Capital in Economic Growth: Evidence from the Semi-industrialized Countries*. Discussion Paper 92–14, University of California, San Diego.

Lucas, Robert E., Jr., 1988, On the mechanics of economic development. *Journal of Monetary Economics*, **22,** pp. 3–42.

Lucas, Robert E., Jr., 1990, Why doesn't capital flow from rich to poor countries? *American Economic Review*, **80**, pp. 92–96.

Mankiew, N. Gregory, David Romer and David N. Weil, 1992, A contribution to the empirics of economic growth. *Quarterly Journal of Economics*, **107**, pp. 407–437.

Michaely, M., 1977, Exports and economic growth: an empirical investigation. *Journal of Development Economics*, **4**, pp. 49–53.

Mincer, Jacob, 1974, *Schooling, Experience, and Earnings*. National Bureau of Economic Research, New York.

Nelson, Richard R. and Edmund S. Phelps, 1966, Investment in humans, technological diffusion, and economic growth. *American Economic Review*, **56**, pp. 69–75.

Pack, Howard, 1994, Endogenous growth theory: intellectual appeal and empirical shortcomings. *Journal of Economic Perspectives*, **8**, pp. 55–72.

Phillips, Peter C. B. and Pierre Perron, 1988, Testing for a unit root in time series regression. *Biometrika*, **2**, pp. 335–346.

Psacharopoulos, George, 1985, Returns to education: a further international update and implication. *Journal of Human Resources*, **20**, pp. 583–597.

Psacharopoulos, George, 1994, Returns to investment in education: a global update. *World Development*, **22**, pp. 1325–1343.

Rebelo, Sergio, 1991, Long run policy analysis and long run growth. *Journal of Political Economy*, **99**, pp. 500–521.

Romer, Paul M., 1986, Increasing returns and long run growth. *Journal of Political Economy*, **94**, pp. 1002–1037.

Romer, Paul M., 1990a, Human capital and growth: theory and evidence. *Carnegie Rochester Conference Series on Public Policy*, **32**, pp. 251–285.

Romer, Paul M., 1990b, Endogenous technological change. *Journal of Political Economy*, **98**, pp. S71–S102.

Solow, Robert M., 1994, Perspectives on growth theory. *Journal of Economic Perspectives*, **8**, pp. 45–54.

Stokey, Nancy L., 1991a, Human capital, product quality, and growth. *Quarterly Journal of Economics*, **105**, pp. 587–616.

Stokey, Nancy L., 1991b, The volume and composition of trade between rich and poor countries. *Review of Economics Studies*, **58**, pp. 63–80.

Tallman, Ellis W. and Ping Wang, 1994, Human capital and endogenous growth: evidence from Taiwan. *Journal of Monetary Economics*, **34**, pp. 101–124.

World Bank, 1991, *World Development Report*. Oxford University Press, New York.

Young, Alwyn, 1991, Learning by doing and the dynamic effects of international trade. *Quarterly Journal of Economics*, **106**, pp. 369–405.

Young, Alwyn, 1995, The tyranny of numbers: confronting the statistical realities of the East Asian growth experience. *Quarterly Journal of Economics*, **110**, pp. 641–680.